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ABSTRACT

A summary of the current Evaporative Removal of Sodium, (ERNA) activities at the Energy Systems Group is presented. Also included is a review of earlier work on sodium evaporation. As a result of this work it was concluded that the ERNA process was extremely successful and worthy of future consideration as a recognized process for reactor components.

Also included in the report is a Preliminary Outline Specification for a large facility to remove sodium from full size CRBR fuel rod assemblies.

This report satisfies Milestone F02 of SA004.

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I. INTRODUCTION

The removal of sodium from components using heat and vacuum had not been investigated thoroughly prior to the initiation of the ERDA (now DOE) activity at Atomics International (now Energy Systems Group) in 1975, although the technique had been used previously in the U.S.A. at the W Advanced Reactors Division to clean various components (Ref. 1). These operations were conducted at temperatures of 427-540°C (800-1000F) and pressures of 1-200 microns (0.13-27 Pa).

Initial tests by Hill at AI demonstrated that successful sodium removal could be accomplished as low as 260°C (500°F) using a diffusion-pumped system capable of attaining 10^{-5} to 10^{-6} torr (1.3×10^{-3} to 1.3×10^{-4} Pa). (Refs. 2 and 3) Use of the lower temperatures also reduced the potential hazards of corrosive attack by the oxides of sodium, as mentioned in Ref. 1.

This task was inactive in fiscal year 1976, but was reinstated in fiscal year 1977. A Test Plan and a Development Test Procedure were prepared to delineate the new vacuum evaporation task (Ref. 4 and 5).

An existing vacuum chamber (Figure 1) was adapted for use as a sodium evaporation chamber and a UTHE Quadrapole Mass Spectrometer was purchased to identify the gaseous species present during the evaporation and to serve as a process control instrument.

The large vacuum chamber, equipped with a 150 mm (6 inch) diameter diffusion pump and a mechanical forepump, was relocated in Bldg. T042. The two pumps were filled with special fluids -- the former with Santovac 5 to prevent damage to the electrometer unit of the mass spectrometer from glassy deposits formed from decomposing silicone diffusion pump fluid, and the latter with Fomblin Y-25 to eliminate the many small molecules, released by the breakdown of ordinary mechanical pump oil which could obscure the mass spectrographic peaks of interest during sodium evaporation.

In addition, special, water cooled sodium-collector plates were fabricated and installed in the chamber to condense and hold the sodium after evaporation.

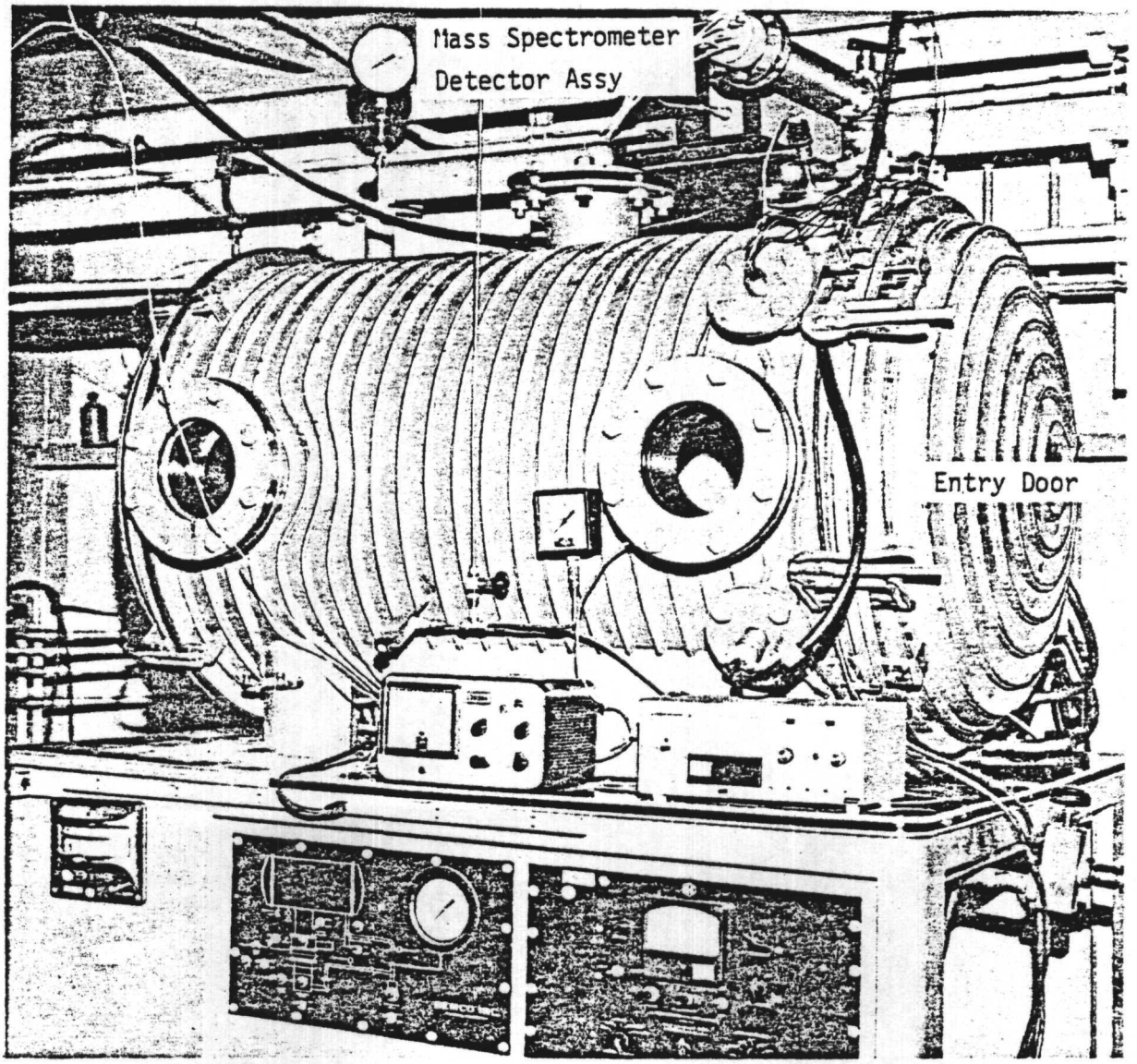

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Figure 1 Vacuum Chamber Used For Sodium Evaporation Studies.

The major activities which were concluded in the first phase of the task were:

A. The Parametric Tests

A series of tests were conducted on tubular specimens (0.3 inch or 7.5 mm diameter) and on crevice specimens (Figure 2) to establish the rates of sodium evaporation and the general operating parameters. Evaluation of earlier test data resulted in the selection of 600F (315C) as the evaporation temperature and 10^{-5} to 10^{-6} torr (1.3×10^{-3} to 1.4×10^{-4} Pa) as the evaporation pressure.

Figure 3 shows the results of the rate tests on the crevice specimens (with crevice dimensions selected to cover the normal range of expected gaps, openings, etc.).

These removal rates were significantly higher than rates calculated from diffusion theory, and the change was found to be caused by expulsion of the sodium from the crevices.

Hill of AI had earlier observed the phenomena of sodium expulsion from crevices which had been mentioned in Ref. 1, to wit, "Even screw thread interstices were found to have been cleared by this method...This was thought to have been due to the displacement by gas bubbles remaining in the threads..." This expulsion is postulated by Hill and Welch to be produced by the release of gases dissolved in the sodium.

One less apparent, but very beneficial effect of the expulsion, is that the expelled sodium carries any impurities to the surface, whereas these impurities (oxides and other materials in the sodium) normally would remain in the crevice as the sodium evaporates. Since the expulsion phenomena is more evident with very small crevices or shrink-fit clearances where solvents or reactants do not penetrate readily, the benefits are even greater. The gases which produce this expulsion have not been fully characterized, but mass spectrographic studies have shown them to be mainly H_2 and methane (CH_4).

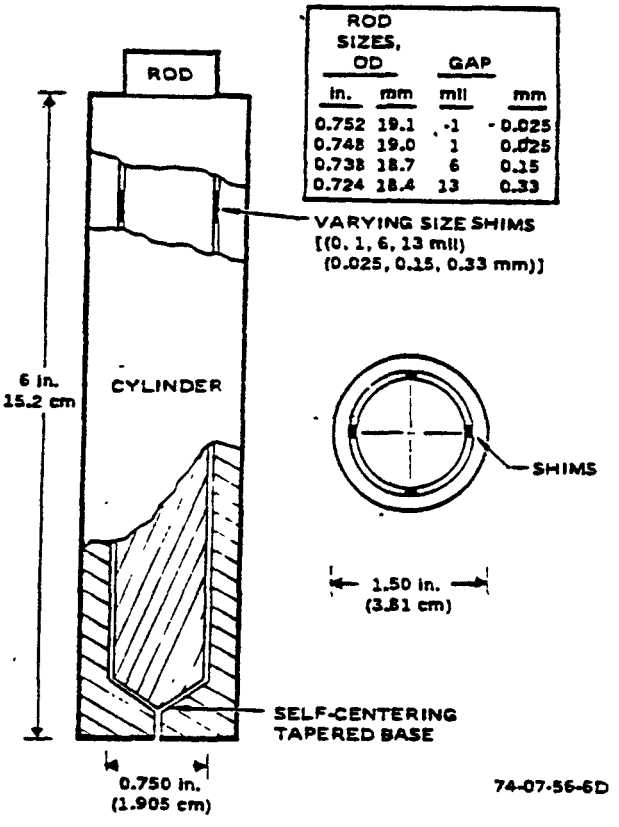

Figure 2 Type 304 Stainless Steel Crevice Specimen

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VACUUM EVAPORATION OF SODIUM FROM CREVICES

316°C (600°F) AND 1.3 x 10-4 Pa (10-5 TO 10-6 TORR)

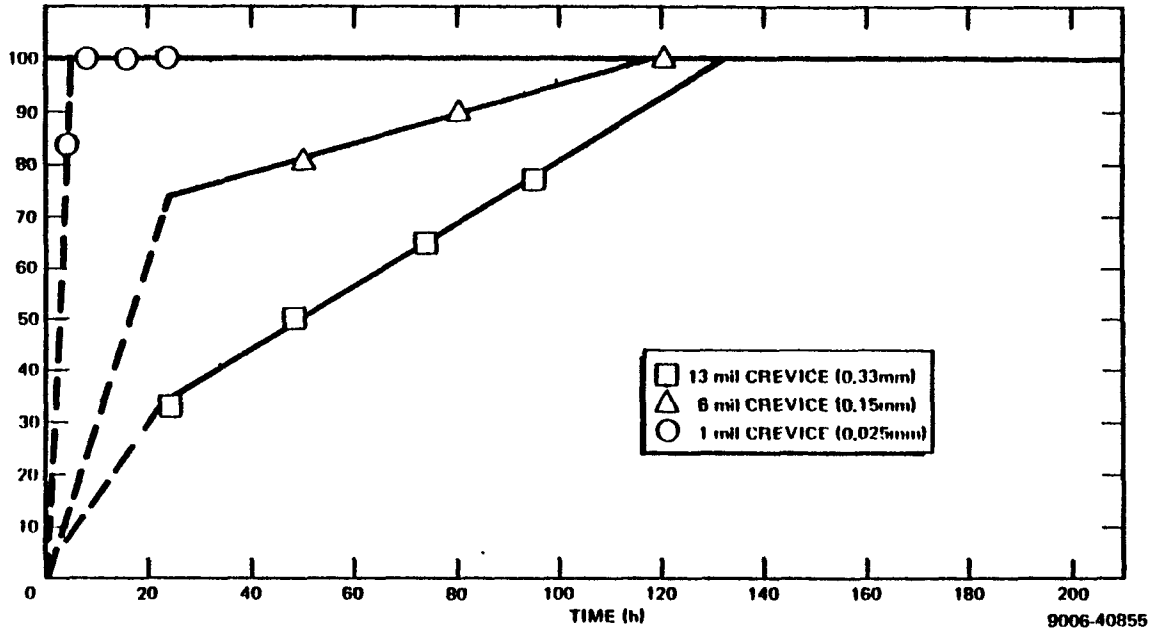

Figure 3

Extrapolation of the curves to "zero" time indicate that about 20% of the sodium is expelled from the 13 mil (0.33 mm) crevice as compared to 65% from the 6 mil (0.15mm) and nearly 100% from the 1 mil (0.025 mm) crevice

Evaporation tests with sodium-filled stainless steel tubes, 0.306 inch ID (7.78 mm), welded closed at the bottom, containing about 4 inches (100 mm) of sodium, produced evaporation rates of 3 mm/hr or more. Table 1 summarizes the rate data obtained from the parametric tests, and includes data from the earlier work of Hill.

TABLE 1

Evaporation Rates of Sodium from Test Hardware
At 316°C (600°F) and 1.3×10^{-3} to 1.3×10^{-4} Pa
(10^{-5} to 10^{-6} torr)

Type Deposit	Size, Width (mm)	(mil)	Removal Rate (mm/h)
Open Pools	--	--	3
Deep Holes	7.5	300	>3
Crevice	0.025	1 or less	30
Crevice	0.15 to 0.33	6 to 13	1
Bolts	0 to 0.025	0 to 1 (gaps)	-- (in 8 h)

It was concluded from these tests that the evaporative removal of sodium (ERNA) process was an extremely promising method of sodium removal from sodium-wetted reactor components. (This work is covered in more detail in Ref. 6)

B. Stress Corrosion Cracking Evaluation

The objective of this task was to establish whether or not the evaporative process caused conditions in Type 304 stainless steel which might result in caustic stress corrosion cracking, since the process removes only the volatile sodium, leaving behind the non-volatile sodium compounds. These compounds would be mainly on the surface of the component, since it has been observed that part of the sodium is expelled from the component crevices during the evaporation, carrying the impurities to the surface or completely away from the components.

These residual sodium compounds, if exposed to water vapor, form highly caustic materials which could cause deleterious effects to hot, stressed parts.

A group of tensile specimens (Figure 4) was fabricated from the same lot of Type 304 Stainless Steel procured and used for a similar test in the Alcohol Process for the Removal of Sodium task (Refs. 6). The specimens were fabricated to AI Drawing N70700018.

The specimens were assembled in individual holders, as illustrated in Figure 5, and wetted with sodium at 1050F for 48 hours. The assemblies were transferred to an N_2 atmosphere box, the tensile specimen lengths measured, and the specimens stressed to 100% of 0.2% offset yield.

The specimens were subjected to two storage conditions (argon store, and air store at 50% relative humidity) prior to the evaporation of the sodium. During the storage period the specimens acquired a layer of sodium compounds on the surface which was not removed by the vacuum evaporation at 600F for 100 hrs at 10^{-5} torr.

Following the evaporative removal of the sodium, the specimens were subjected to several different conditions, to provide environments which might instigate caustic stress corrosion cracking. When the holders were disassembled at the end of the test, no trace of metallic Na was observed. The specimens were cleaned of any Na compounds and tensile tested to determine the effects of the treatment on their mechanical properties.

No evidence is found from the mechanical property data or from examination of the photomicrographs that the Evaporative Removal of Sodium (ERNA) Process causes any harmful effect to the Type 304 stainless steel, even though many of the exposure conditions are out-of-control, that is, the specimens were exposed to conditions which would not occur during normal evaporative processing.

It must be concluded from these tests that the Evaporative Removal of Sodium (ERNA) Process does not cause harm to stressed, sodium-wetted Type 304 stainless steel, even though many of the specimens were exposed to conditions which would not be encountered during normal processing, such as exposure to 50% relative humidity air, and air baking at elevated temperatures. (This work is covered in more detail in Ref. 8.)

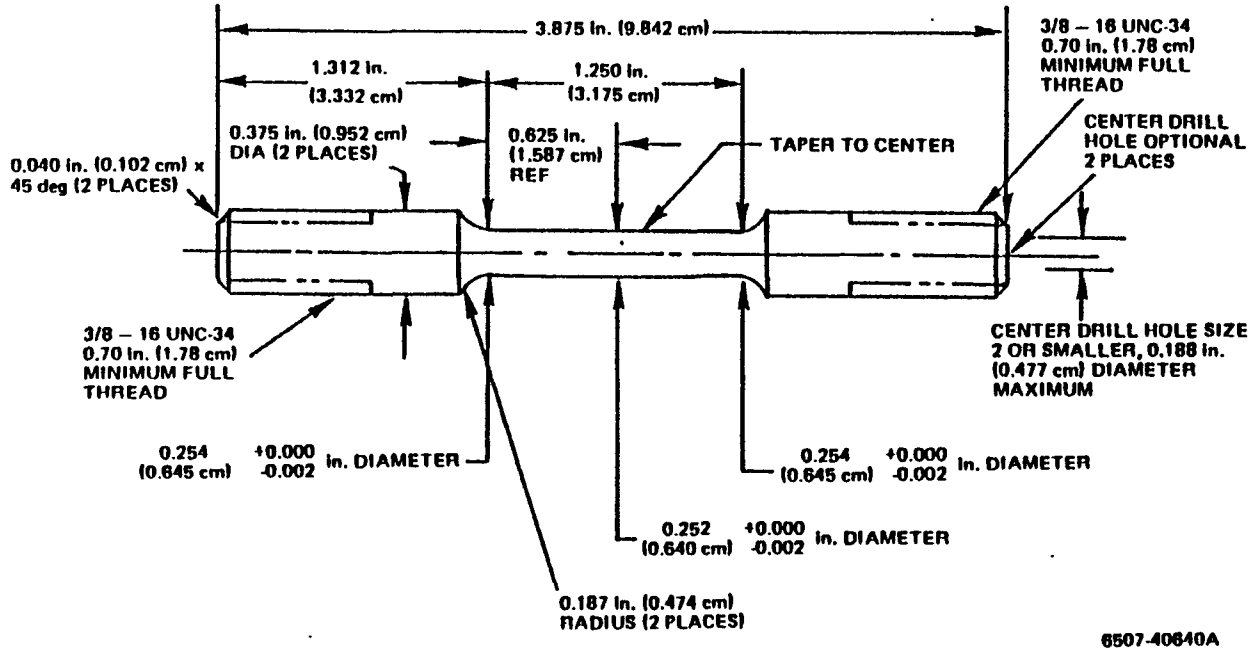

Figure 4 Tensile Specimen for Stress Corrosion Test

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CAUSTIC STRESS CORROSION TENSILE SPECIMEN

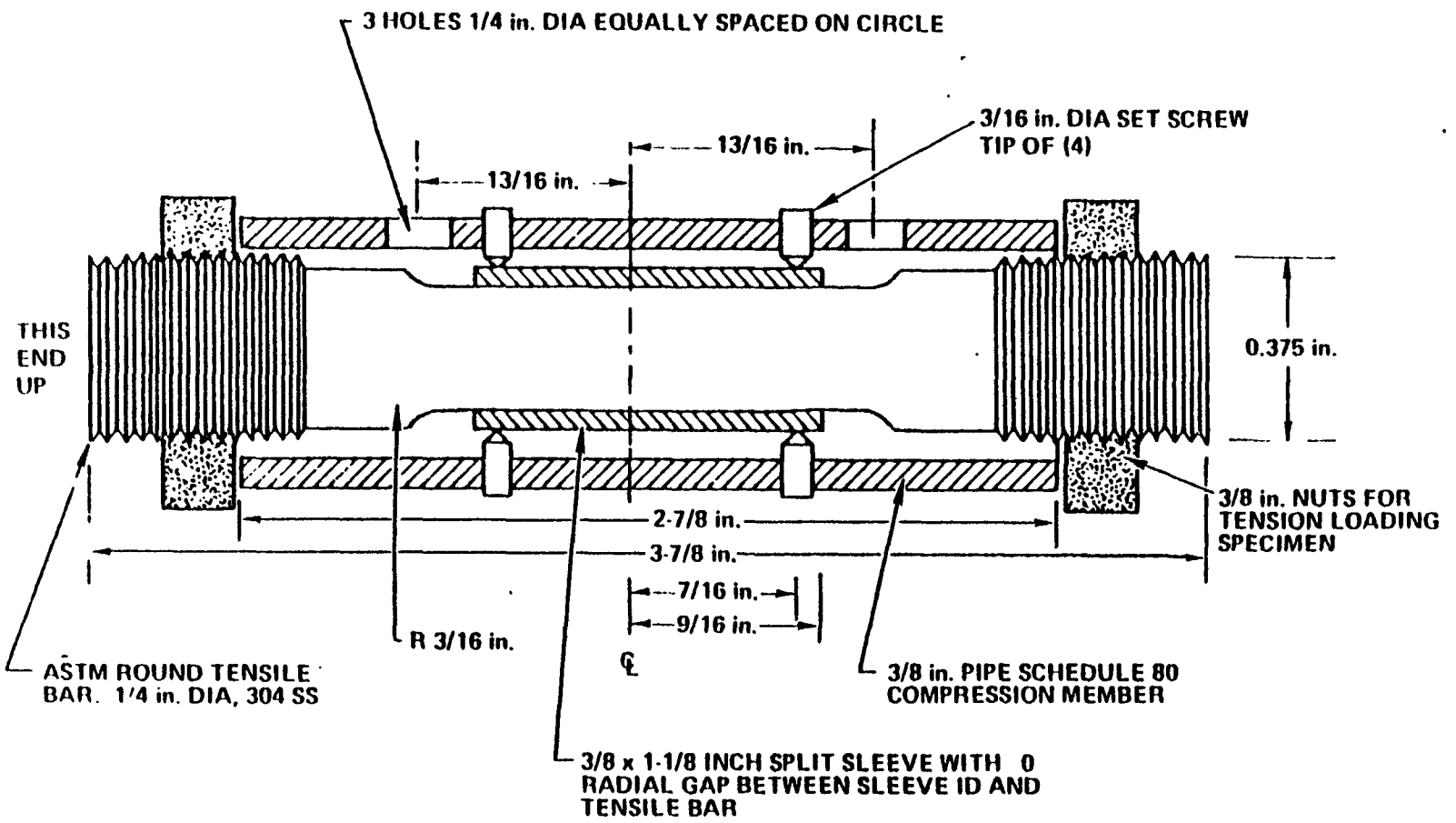

Figure 5

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C. IHX Tube Bundle Mockup

The objective of this task was to demonstrate the ability of the evaporative process to remove sodium (Na) from a complex component.

The test article was the IHX Tube Bundle Mockup (Figure 6) which had been used previously in the demonstrations of the Alcohol Process and the Water Vapor-Nitrogen Process for the removal of sodium (Refs. 9 and 10

The IHX Tube Bundle Mockup was cleaned, assembled, and transferred to the large vessel of the Bldg. 006 Santa Susana Sodium Loop, where it was soaked in 1050F Na for 48 hours. The Na-wetted component was bagged under inert gas and moved to Bldg. 042, where it was transferred into the vacuum chamber. The component was placed in the Na-collector panel box between two large flat-plate heaters, specially built for the operation.

The vacuum system was sealed and the chamber pumped down to 10^{-6} -10^{-7}torr. The heaters were turned on and the temperature increased to 600F. Since the component was massive, and held much more Na than normally handled by the system, the large quantities of evolved gases raised the pressure to $\sim$1 x 10^{-4}torr for a short time. However, the 6-inch diffusion pump soon lowered the pressure to about 1 x 10^{-5}torr, and throughout the majority of the 100-hour cycle the pressure was $\sim$3 x 10^{-6}torr.

At the end of the cycle, the heater power was turned off and the component cooled to room ambient. The vacuum chamber was back-filled with N_2, and the component removed for examination.

No evidence of metallic Na could be found, but, since Na compounds are not removed by the evaporative process, a thin layer of these materials (NaOH, Na_2CO_3, etc.) was observed on the surfaces which had been exposed to the inert gas atmosphere during handling. The inert gas atmosphere, although of high purity, contains trace (few ppm) amounts of O_2, CO_2, and water vapor which reacts rapidly with the fresh Na surface.

The unit was left in the room atmosphere for three weeks, but no evidence of "bleed-out" was observed from tight crevices which could not be disassembled for examination.

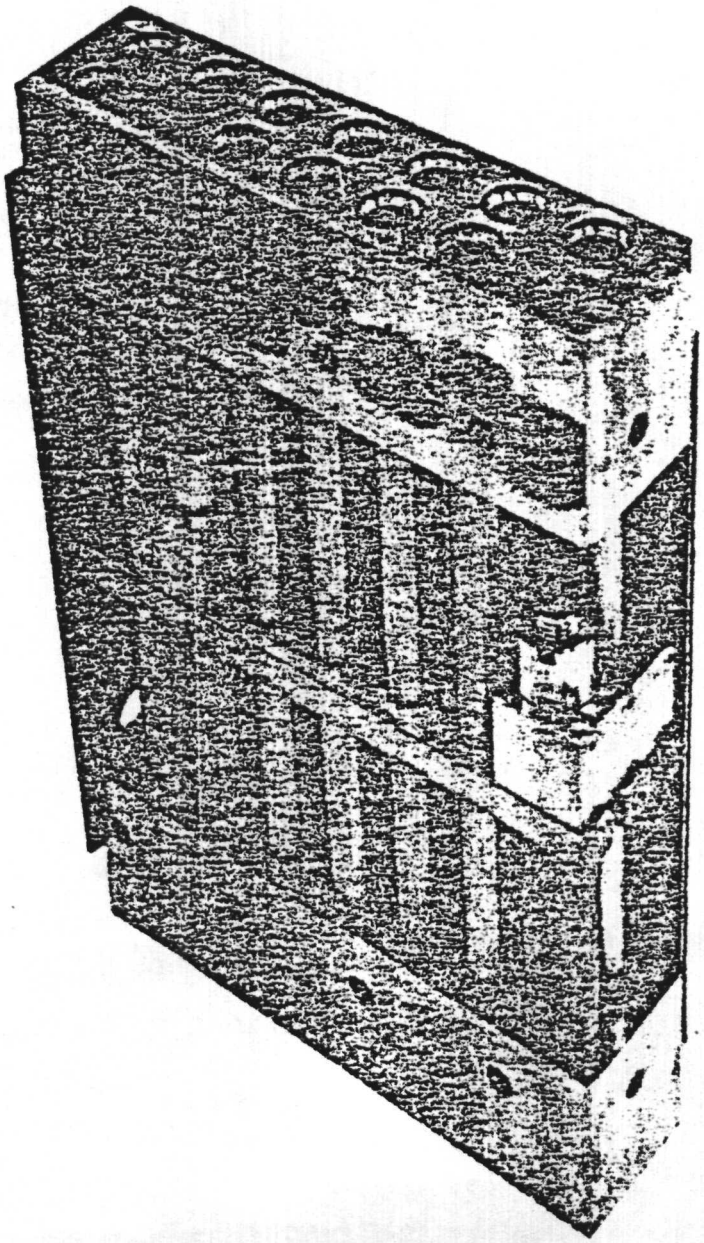

Figure 6. IHX Tube Bundle Mockup

The water-cooled Na-collector plate assembly was found very effective in collecting the Na and preventing its spread throughout the system. The Na which does escape the collector plates gathers on the water-cooled walls of the vacuum chamber.

Only extremely small amounts of Na escaped the system to reach the mass spectrometer system which is capable of reading parts per billion concentrations of gaseous species.

The successful removal of Na from the IHX Tube Bundle Mockup confirmed the ability of the Evaporative Removal of Sodium (ERNA) Process to clean complex geometrics at relatively low temperatures (600F) and at pressures easily obtainable with modern diffusion pumped systems. (This work is covered in more detail in Ref. 11.)

At the conclusion of this phase of the task a preliminary outline specification was prepared for the evaporative removal of sodium from components (Ref. 12).

II TEST RESULTS IN FY 1978

A. Failed Fuel Pin Assemblies

The evaporative removal of residual sodium from the Clinch River Breeder Reactor (CRBR) spent fuel and core component assemblies (Fig. 7.) by blowing hot, dry argon through the assemblies had been studied earlier (Ref. 13-15). This method was indicated to be practicable for removal of residual sodium on the exterior surfaces in the assemblies. However, removal of sodium that has leaked into fuel pins through cracks in the fuel pin cladding would be a very slow process by this method if the cracks were small, inasmuch as this sodium is removed only by diffusion of sodium vapor out through the small cracks.

Considering the success of the vacuum evaporation process at the Energy Systems Group (ESG), this method was suggested for the removal of residual sodium from both the inside of failed fuel pins and the outside surfaces of all fuel pins by subjecting the fuel assemblies to both convective evaporation and vacuum evaporation in a cyclic manner. The fuel assembly would be cooled with flowing inert gas; then rapidly exposed to vacuum atmosphere, during which time the assembly heats up due to decay heat

generation. Before the assembly overheats, inert gas flow would be restored to cool the assembly. This process would be repeated until the residual sodium is removed.

A program had been funded by ERDA (now DOE) in FY 1977 to perform analysis of the feasibility of this method for the removal of residual sodium from CRBR spent fuel assemblies containing failed fuel pins. This analysis showed, based on the evaporative data and experience, that the process was extremely promising and it was calculated that ∽ six cyclic applications of argon and vacuum would be adequate to remove the sodium from the inside of a failed fuel pin (Ref. 16).

Appendix 1 presents a description of the CRBR Fuel Assembly, and Figs. 8-11 show the results of the calculations. From these calculations, it was further shown that using argon as the cooling media, a 15 minute cooling period would be required and a 10 minute evacuation cycle would be possible, whereas using helium gas, a 10 minute cooling period would be required, followed by a 13 minute evacuation cycle before the fuel element temperature reached the 677°C (1250°F) maximum.

In fiscal year 1978, a task was funded at ESG to establish the feasibility of the evaporative removal of sodium at the hardware stage using simulated fuel assemblies containing a failed fuel pin, and lay the ground work for a safe, reliable and fast method for fuel element cleaning prior to disassembly.

Using the information given in Figure 7 and Appendix 1, simulated fuel pin assemblies were built, as shown in Figure 12. The simulated fuel pins were wire-wrapped and their ends crimped and welded shut. An assembly of eight fuel pins and one open stainless tube (heater lead return) were banded around an inner stainless steel tube which holds the heater used to simulate the gamma heating of actual fuel pins. A later modification -- the use of a cartridge heater in the central tube -- eliminated the small heater lead return tube which was replaced by a fuel pin.

Before being welded shut, one of the fuel pins in each bundle was slotted with a thin wheel to produce a 0.015 inch wide slot about 1/2 inch long to simulate the pin failure, and a filler rod added to simulate the volume of the fuel.

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CRBR FUEL ASSEMBLY

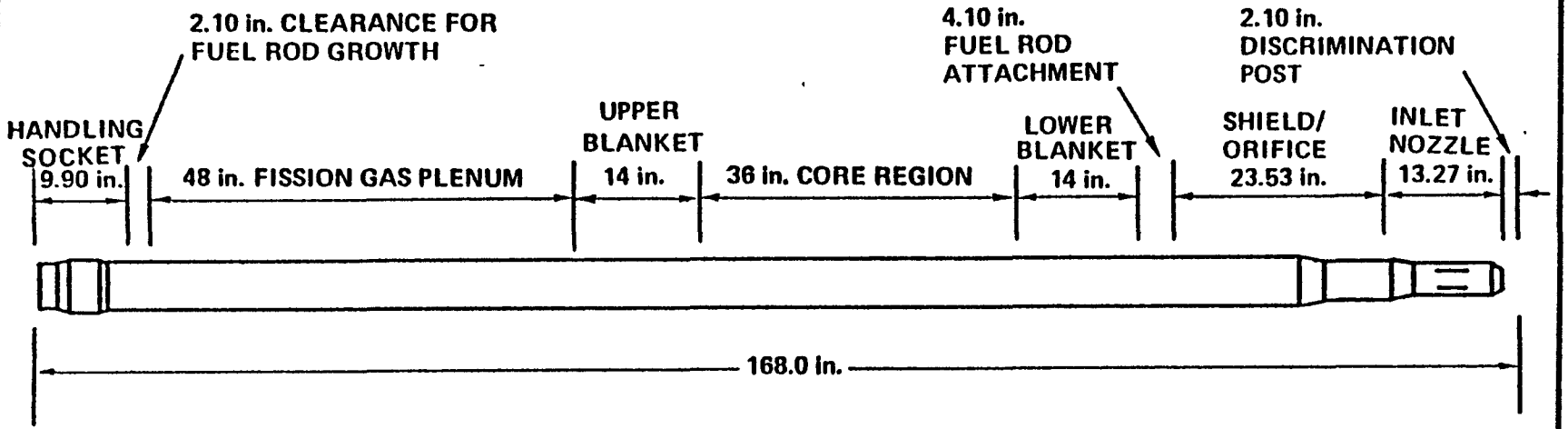

Figure 7

FUEL PIN CLADDING TEMPERATURES FOR CASE OF ARGON COOLING

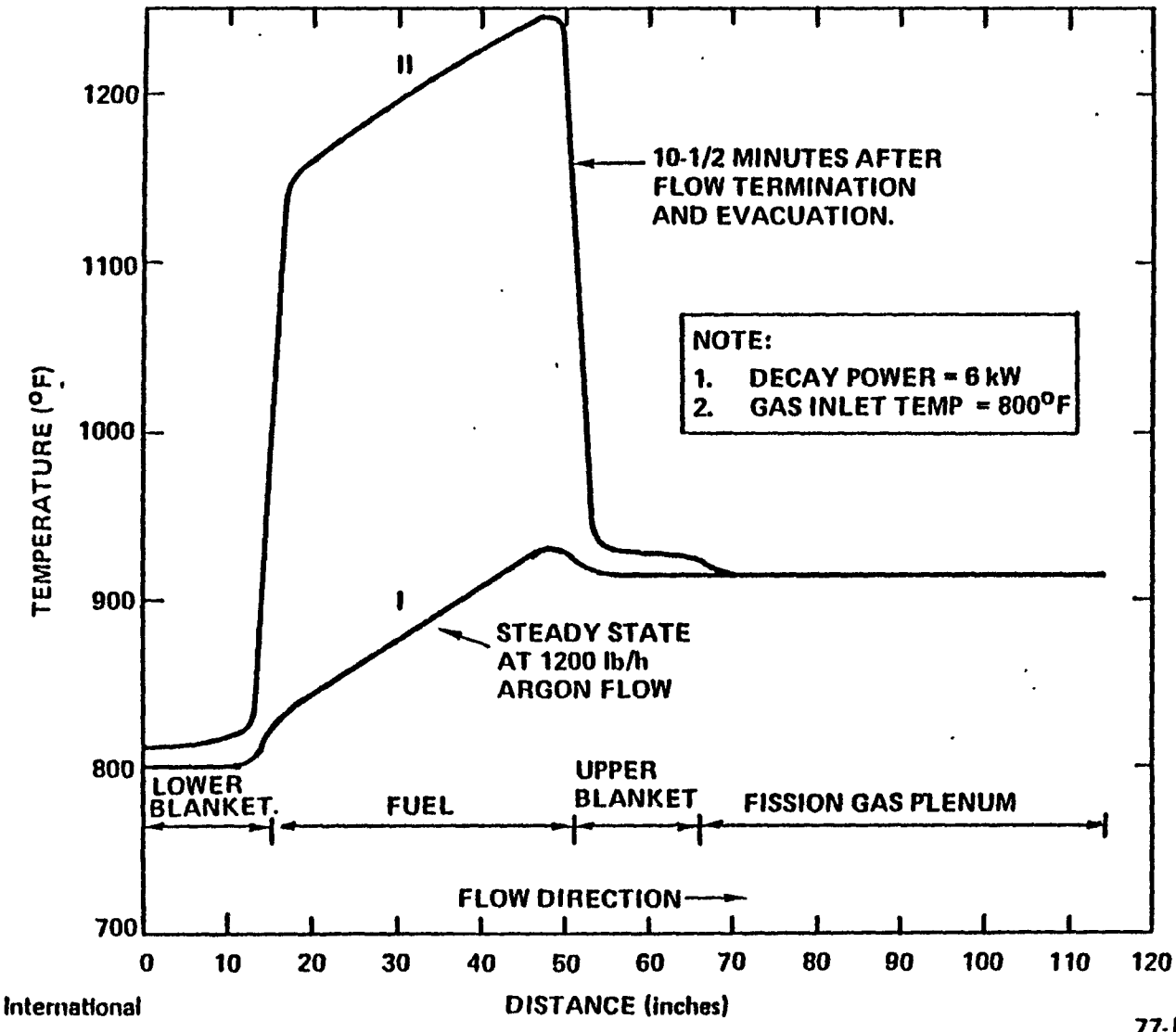

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Figure 8

TIME REQUIRED TO REDUCE MAXIMUM CLADDING TEMPERATURE FROM 1250°F TO STEADY STATE VALUE WITH 1200 lb/hr ARGON FLOW

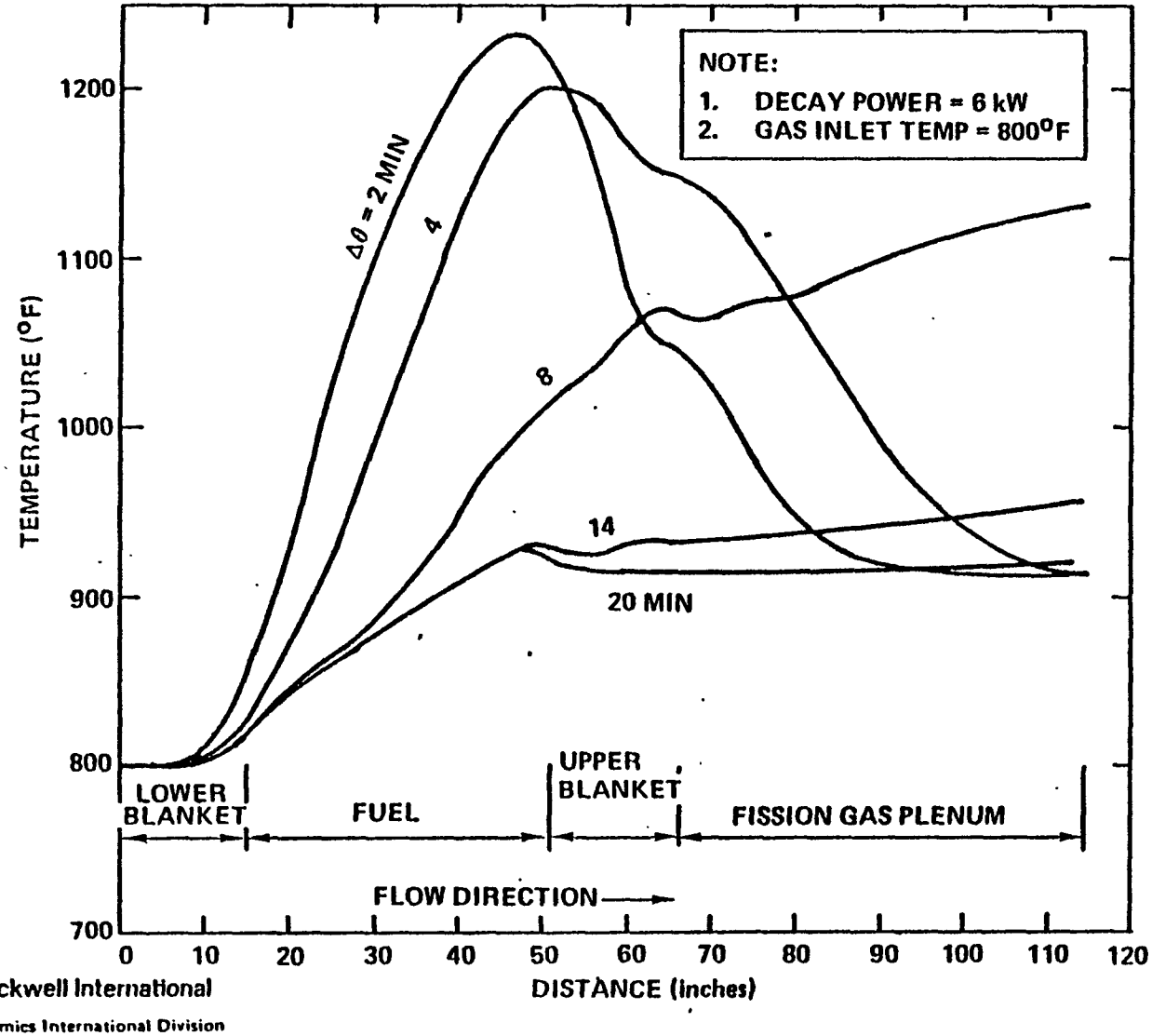

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Figure 9

FUEL PIN CLADDING TEMPERATURES FOR CASE OF HELIUM COOLING

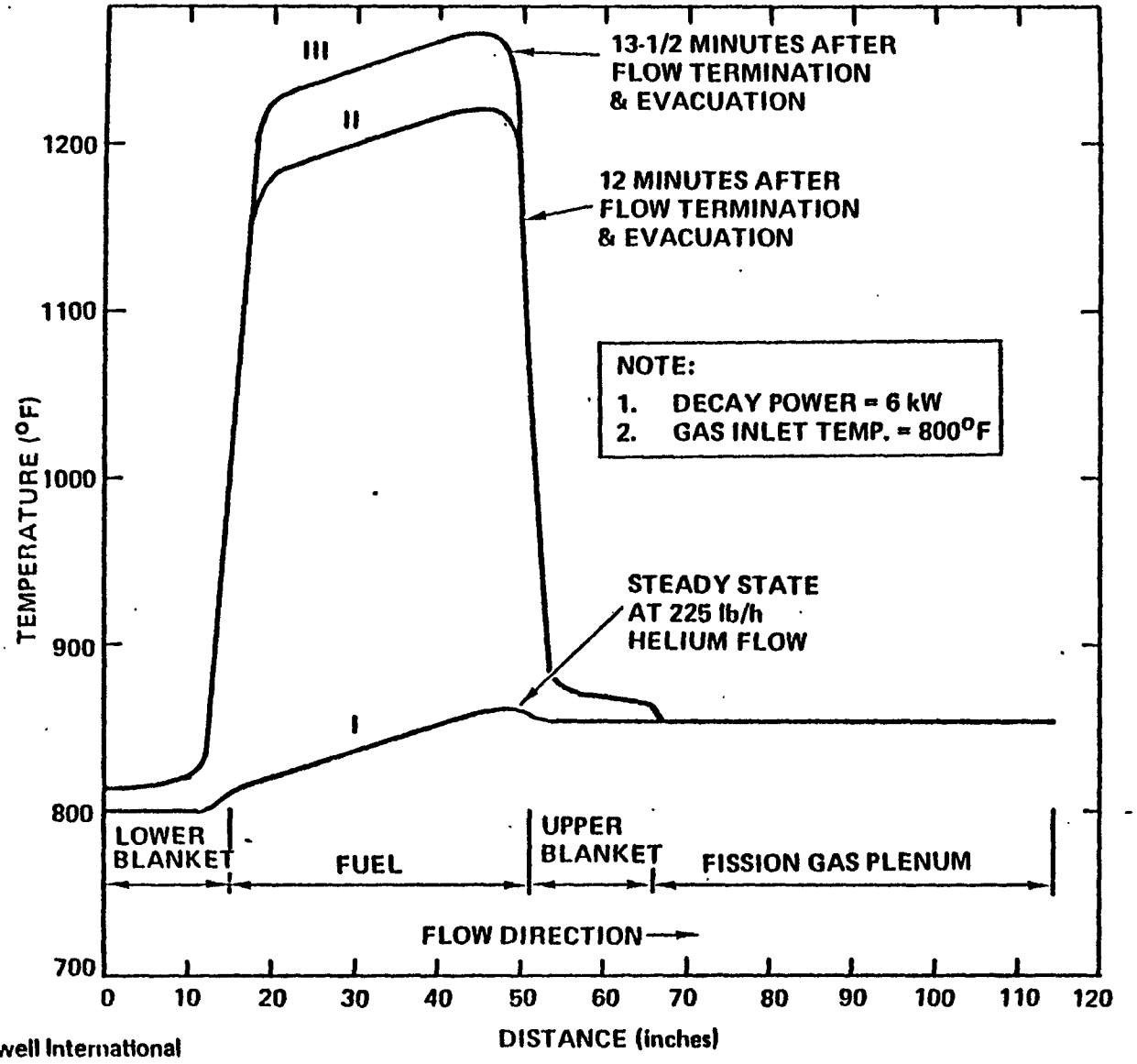

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Figure 10

TIME REQUIRED TO REDUCE MAXIMUM CLADDING TEMPERATURE FROM 1250°F TO STEADY STATE VALUE WITH 255 lb/hr HELIUM FLOW

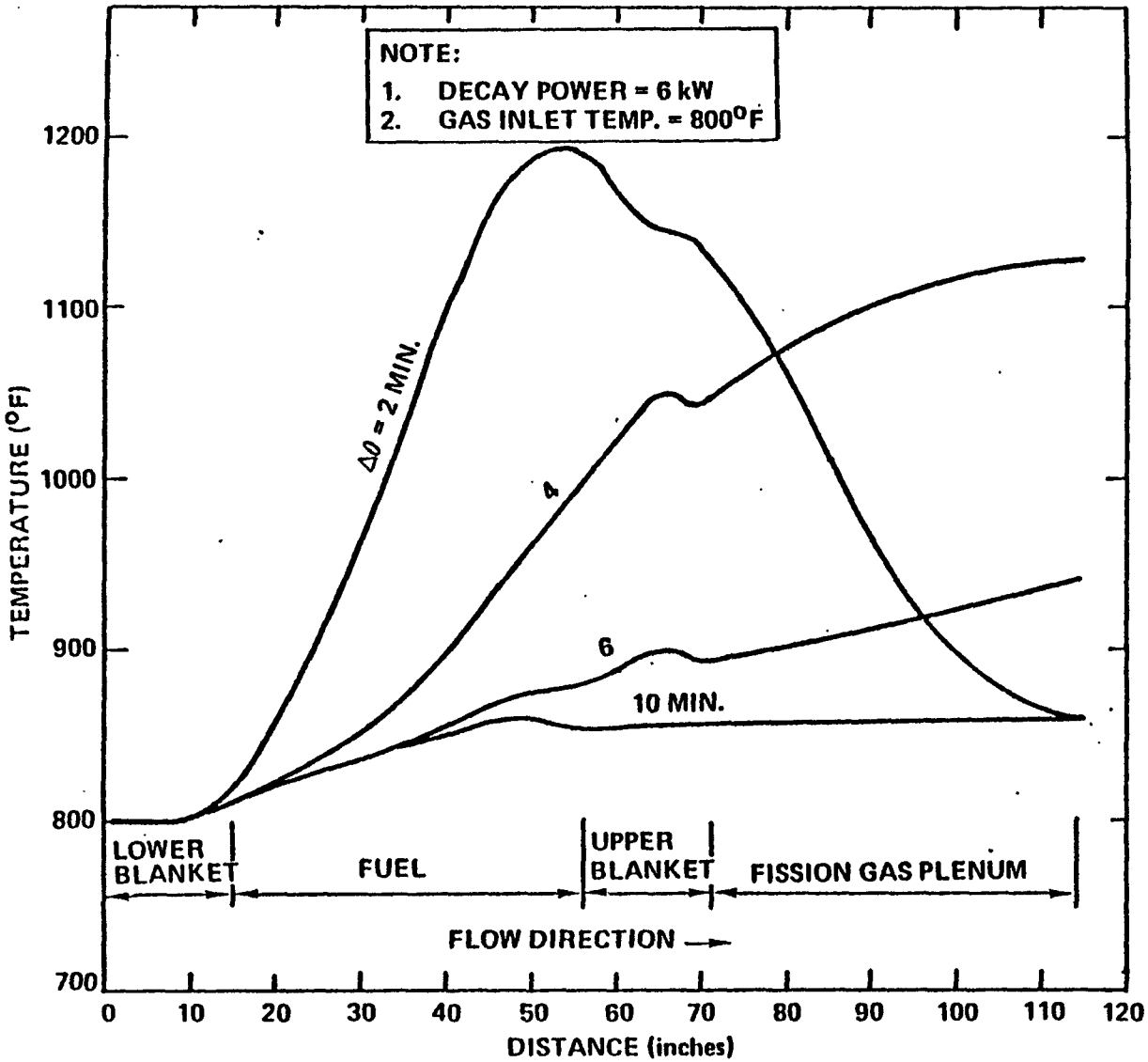

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Figure 11

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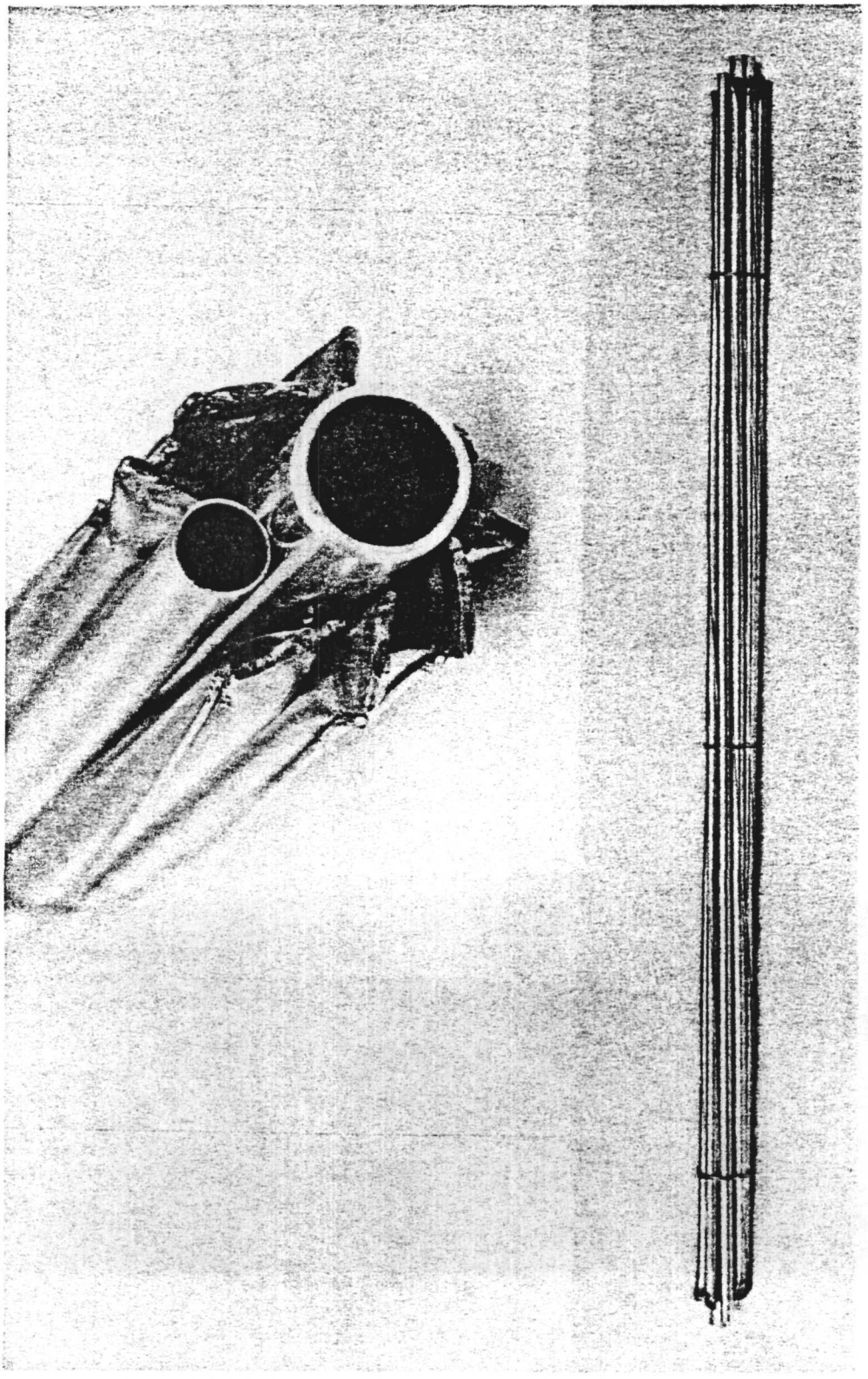

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SIMULATED FAILED FUEL PIN ASSEMBLY
FOR SODIUM REMOVAL TESTS

Figure 12

The existing vacuum system in Bldg. T042 (Figure 1) was modified by the addition of a high vacuum valve and a T-section to an existing bottom flange. To the T-section were added other components, as shown in Figure 13, including a 300 cfm Stokes vacuum pump and the special evaporation section, shown in Figure 14, which contains the simulated fuel pin assembly during the test.

Also added to the T-section was a high vacuum valve and a 1600 l/s Sargent-Welch turbomolecular pump. The addition of the T-section permitted the existing vacuum system and the new Failed Fuel Sodium Evaporation System to be interconnected and the vacuum equipment to be used with either system.

A Test Plan and Development Test Procedure (Ref. 4 and 17) were prepared presenting the overall plan and the detailed operations. The assembly, checkout and test procedures are shown in Appendix 2.

A Preliminary Outline Specification also was prepared based upon the information available before the start of the test program (Ref. 18). This specification was revised at the conclusion of testing and issued as a Final Outline Specification (Ref. 19).

The first (and all subsequent) simulated failed fuel pin assembly was wetted with sodium at 648-677C (1200-1250F) for 48-72 hr., and loaded into the evaporation vessel with the defect in the up position. The assembly was heated to about 650°C (1200°F) in the argon atmosphere, and then cooled to 427-482°C (800-900°F) under an 427°C (800°F) argon flow of 2.8×10^{-3} m^3/s (6 cfm).

During the argon phase of the cyclic application, sodium vapors were observed at the exhaust line, but the white vapors disappeared when the water scrubber system was turned on.

The valves were closed when the system stabilized, terminating the argon flow. The evacuation cycle was begun using only the large Stokes vacuum pump, and the system evacuated to about 1.33 Pa (10 microns) pressure.

When the temperature of the fuel bundle assembly reached about 650°C (1200°F) in the vacuum cycle, the vacuum valves were closed and the

argon flow restarted. Again, the flowing, hot (427°C or 800°F) argon was used to cool the assembly to 427-482°C (800-900°C), before reapplication of the vacuum cycle. (Note: Heater power had been left on to simulate gamma heating.)

On the fourth cycle, the heater power failed and the test was terminated. The fuel pin bundle was found to be completely free of sodium. The slotted fuel pin which simulated the failed pin was cut open and examination showed the sodium to be completely removed from the inside of the tube. (Figure 15). Both the inner rod and an adjacent pin show spots of discoloration, although there was no visual evidence of metal damage. The spot on the adjacent pin was probably caused by the Na spraying onto the pin surface as it exited the wetted tube.

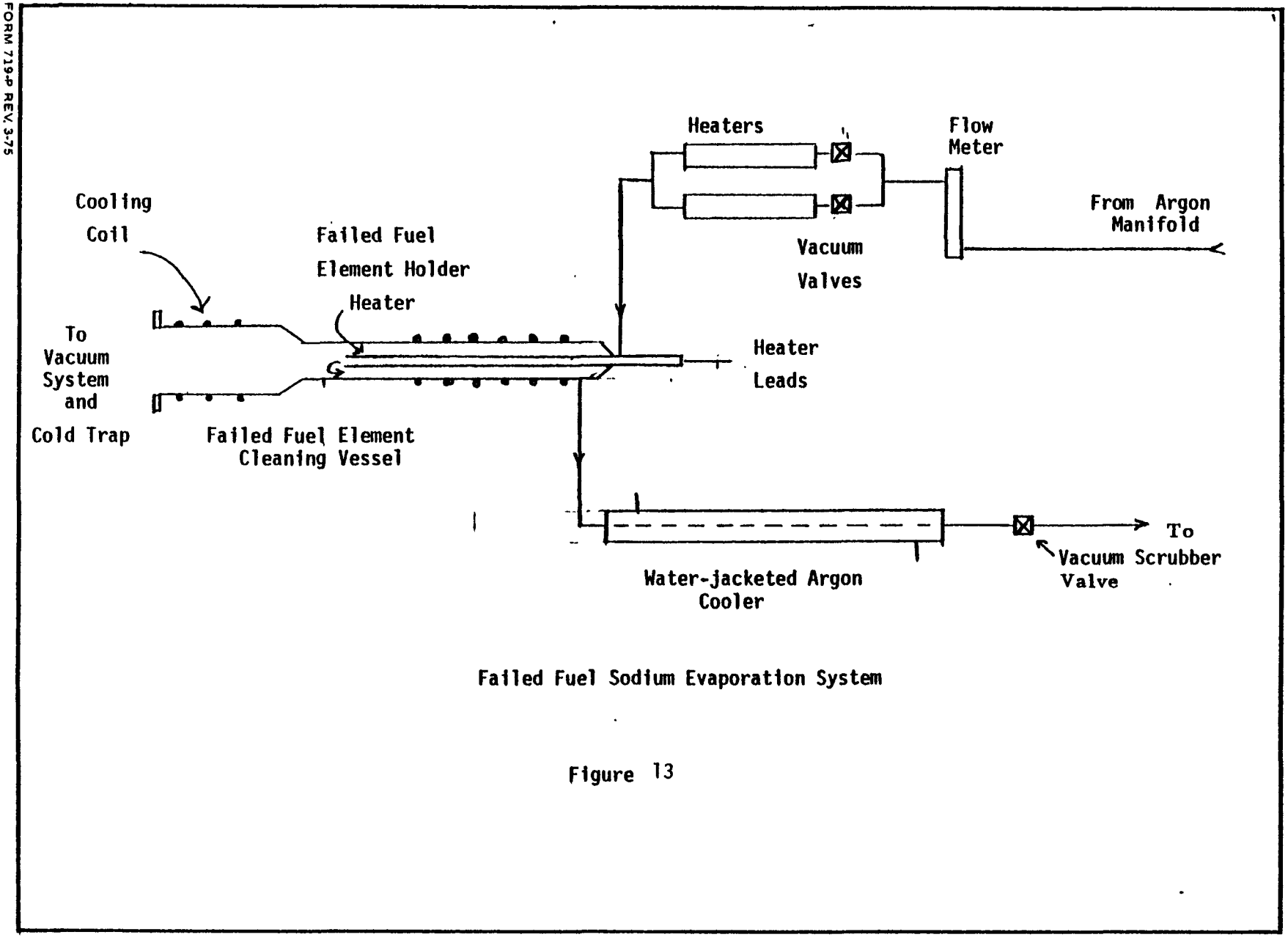
Failure of heater power was found to have occurred in the lead and not in the heater. The system was modified after the heater lead failure by welding the terminal end of the heater into a stainless steel tube which connected into the system with a Swagelok fitting, leaving the heater lead in the air, rather than in the argon/vacuum atmosphere. This modification eliminated the arcing problem and the system functioned satisfactorily.

Six additional heated runs were made on sodium-wetted, simulated, failed fuel pins. The initial run was a repeat of the first run when the heater lead failed during the fourth vacuum cycle. Again the simulated, failed fuel pin was found to be free of sodium.

The second run was made with only three argon/vacuum cycles, and again the pin was found to be free of sodium. In all cases, the assembly was cooled to 427-482°C (800-900°F) with 427°C (800°F) argon flowing at 2.8×10^{-3} m^3/s (6cfm), and the assembly was heated to 650-677°C (1200-1250°F) under a pressure 1.33 Pa (10 microns) during the vacuum cycle.

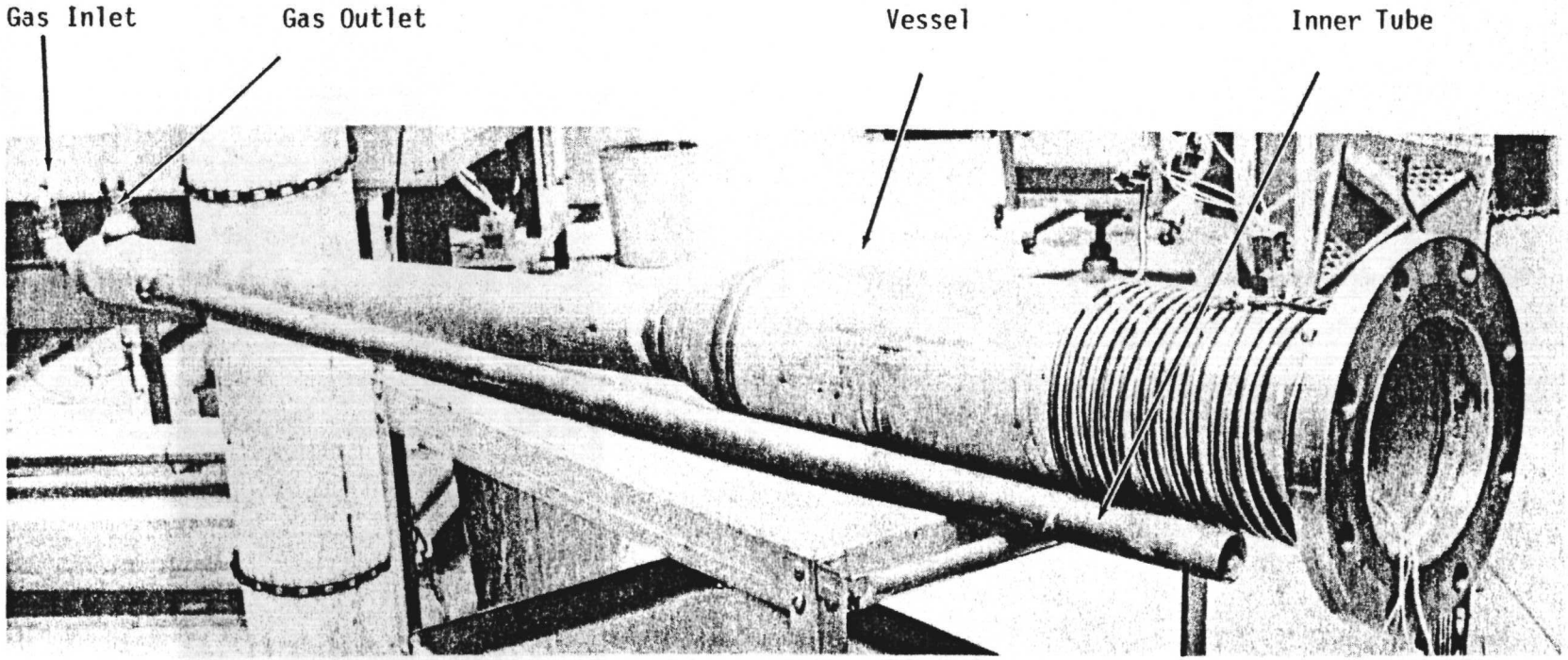
Each cycle required about 45 minutes (30 minutes flowing argon and 15 minutes vacuum).

A third run was made using only flowing argon for 5-1/2 hours. The assembly was held at 427-482°C (800-900°F) as were the other tests. At the



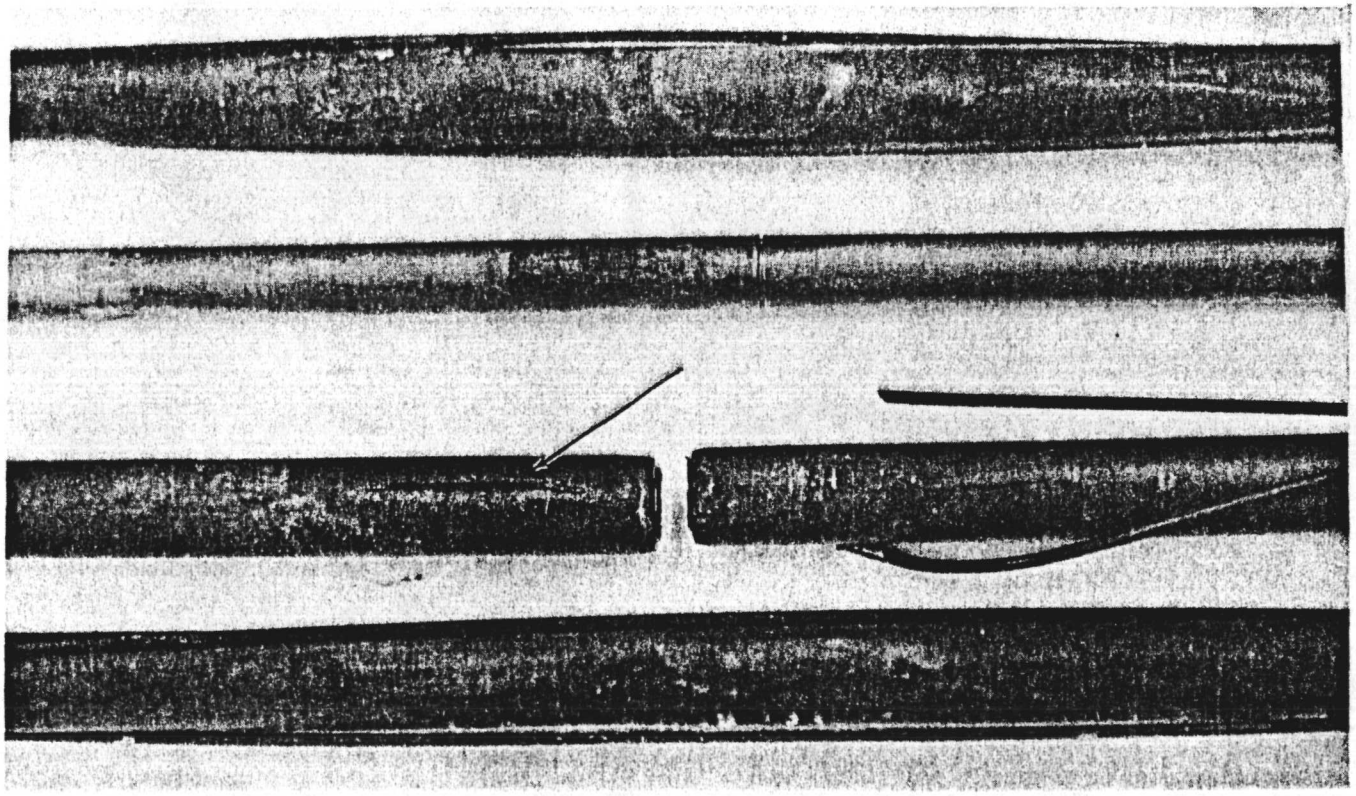
Failed Fuel Sodium Evaporation System

Figure 13



Failed Fuel Assembly
Sodium Evaporation Vessel

Figure 14



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Simulated Fuel Pin Showing Slotted
Pin and Inner Rod

Figure 15

completion of the test, the assembly and the simulated failed fuel pin had residual sodium, showing psoitively that the application of the vacuum cycle is mandatory to produce complete sodium removal.

Two runs of 1 and 2 argon/vacuum cycles were made to establish the minimum number of cycles required to completely remove the Na from inside the pin with the slot defect. In both cases, the pin was found to be free of Na.

A sixth run was made with only one argon/vacuum cycle, but in this case, the slot was closed, after filling the pin with Na, by tapping with a ball peen hammer, as shown in Figure 16. The small openings at the ends of the closed slot do not extend through the pin wall, as the slot was cut with a circular wheel which left a groove on the outer surface much longer than the slot. Post test examination showed the pin to be free of Na.

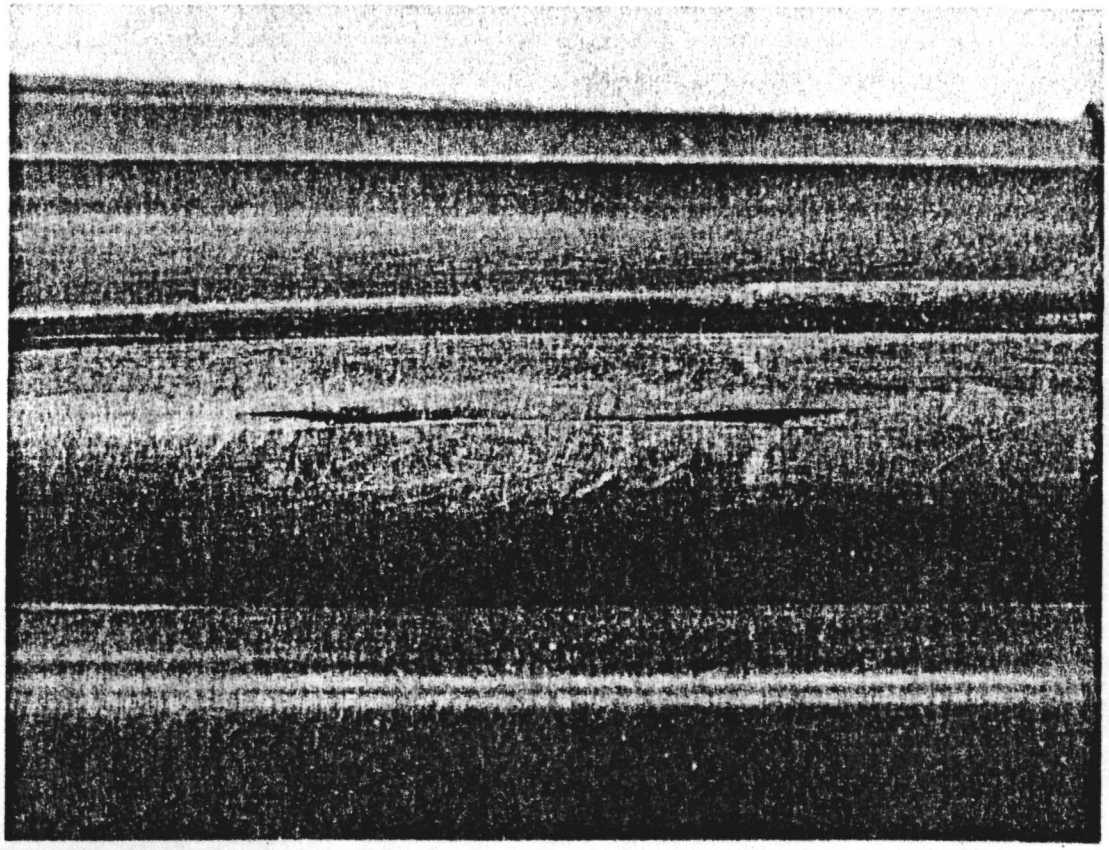
Table 2 summarizes the failed fuel pin assembly evaporation runs. As may be seen, the presence of the vacuum cycle is mandatory, although only one vacuum cycle has been necessary to completely remove the Na from inside the fuel pin.

TABLE 2

Summary of Simulated Failed Fuel Pin Tests
427°C Argon, 2.8×10^{-3} m^3/s (6 cfm) flow for
30 min., 1.33 Pa (10 microns) pressure for 15 min.

	No. of Cycles		Results
Run #	Argon	Vacuum	
1	4	3*	All Na Removed
2	4	4	All Na Removed
3	3	3	All Na Removed
4	2	2	All Na Removed
5	1	1	All Na Removed
6	1	1**	All Na Removed
7	1***	0	Residual Na

*Heater lead failed during vacuum cycle
**Slot "ball-peened" shut
***5-1/2 hr. cycle



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Simulated Failed Fuel Pin

With Slot "Ball-Peened" Closed

Figure 16

To verify the presence and amount of Na inside the slotted pin, two pins were wetted at 565°C (1050°F) for 48 hr. The first was cut open in several places, and the inside was found to be filled with Na, except for a small void near one end.

A second pin, wetted at a different time, was cleaned of Na on the outside. The difference between its initial weight and its weight after filling with Na was 3.62g. It is assumed from these tests that all of the slotted fuel pins contain Na on the inside after wetting.

During the Na evaporation tests, it is observed that, as planned, the majority of the sodium collects on the water-cooled walls of the evaporation vessel or on the water-cooled cold trap. Although white sodium aerosol is observed at the system exhaust, the quantity of sodium in the aerosol probably is small.

It was concluded from these tests that the feasibility of removing sodium from failed fuel pins by the use of a cyclic application of flowing argon and vacuum has been demonstrated. The sodium removal has been shown to be rapid and efficient. Further, the tests demonstrated that the simulated failed fuel pins used in the testing could be cleaned of Na in only one cycle, although it is possible that actual fuel pins may require multiple cycles dependent upon crack size and geometry, and the internal configuration of the fuel pin.

All testing was performed with the fuel pin assembly in the horizontal position and the pin defect located at the top of the pin (to eliminate gravity effects). It is believed that positioning the fuel pin in the horizontal attitude takes greater benefit of the expulsion phenomena than does positioning in the vertical position, as reported by investigators from Interatom (Ref. 20).

Also, use of a large capacity pump, and large vacuum lines, as were used in these tests, produce rapid removal rates, whereas use of smaller equipment and lines would make the rate dependent upon the vapor pressure of sodium at the evaporation temperature. The work is also described in Ref. 21.

B. Effects of Exposure to Humid Air

The fiscal year 1978 task was expanded to include investigation of the effects of exposure to water vapor and air on the evaporative removal of sodium from components. The earlier test plan and test procedure were revised to cover the new activity (Refs. 22 and 23.)

The tests were planned to use the available crevice and tubular specimens from the parametric studies, and to measure the removal rates on specimens exposed to ambient air for varying lengths of time to simulate accidental exposures.

A group of stainless steel crevice specimens and tubular specimens were prepared and wetted in the sodium at 565°C (1050°F) for 48 hours. The crevice specimens were exposed to ambient air for 24 hours prior to the evaporative removal operation. During the exposure period, the temperature varied from 18-24°c (65-75°F) and the relative humidity was $45 \pm 10\%$.

Table 3 shows the summary of seven evaporation runs at ~315°C (600°F) and 1.3×10^{-3} to 1.3×10^{-4} Pa (10^{-5} to 10^{-6} torr), and also lists the earlier data on specimens which were protected with N_2 atmosphere when handled. The reduction in the % completion, or amount of sodium removal, was not significant, except in the case of the 1-mil specimens.

One serious effect of the exposure to air was the difficulty of removing the pin from the 1-mil crevice specimens. The layer of impurities in the narrow gap required the use of a table vise and a large wrench, whereas normally the pin may be lifted out easily.

From these tests, it may be concluded that the 24 hour exposure does not retard the sodium removal rate significantly, but may create mechanical problems of disassembly. For example, bolts which have been exposed to air for a day might be free of sodium after evaporation, but might be difficult to disassemble.

Seven tubular specimens, ~0.3 in internal diameter by six in. long, were wetted and filled with sodium at ~1050°F for 48 hours. The specimens were exposed to air for 2, 4, 8 and 24 hours respectively [air temperature 18-24°C (65-75°F), relative humidity $45 \pm 10\%$] and then processed at 315-325°C (600-620°F) and 1.3×10^{-3} to 1.3×10^{-4} Pa (10^{-5} to 10^{-6} torr) for 15 to 29 hours. Table 4 lists these test results, and shows the rate for a similar N_2 protected specimen.

TABLE 3

SUMMARY OF EVAPORATION TESTS ON CREVICE SPECIMENS AFTER EXPOSURE TO AIR FOR 24 HOURS. EVAPORATION CONDITIONS: 315°C (600°F), 1.3×10^{-3} to 1.3×10^{-4} Pa (10^{-5} to 10^{-6} Torr)

Crevice Width Mil	Evaporation, Hrs	Completion %	Completion, %, On Unexposed Specimens
1	10	60	100
1	24	36	100
6	50	90	83
6	96	85	93
13	33	40	39
13	60	60	56
13	112	100	86

TABLE 4

SUMMARY OF EVAPORATION TEST ON TUBULAR SPECIMENS AFTER EXPOSURE TO AIR FOR 2, 4, 8 AND 24 HOURS. EVAPORATION CONDITIONS: 315°C (600°F) and 1.3×10^{-3} to 1.3×10^{-4} Pa (10^{-5} to 10^{-6} Torr)

Exposure to Air, Hr	Evaporation hrs	Rate in /hr	Rate mm /hr
0	50	>0.12	> 3
2	15	>0.31	>7.9
2	29	>0.16	>4.1
4	29	>0.16	>4.1
8	15	>0.20	>5.1
8	29	0.16	4.1
24	15	0.29	7.4
24	29	0.11	2.8

As may be seen, air exposures of up to 4 hr had no significant effect on the removal rate. (Note: An actual rate cannot be calculated when all of the sodium is removed, since the true time to remove the Na may occur before the test was completed). Again it must be concluded that the presence of a limited amount of oxide and hydroxide impurities does not impair the removal rate. Eight to twenty-four hours of exposure of the sodium to humid air does result in an erratic removal rate which may be less than that of protected specimens. However, the removal rate is still quite rapid (3-7 mm/hr).

The final test of the fiscal year was with a simulated failed fuel pin bundle which was exposed to humid air for 30 hours prior to evaporation. The surface of the bundle was heavily contaminated with oxides and hydroxide when loaded into the evaporation vessel, and was further contaminated when the argon exhaust line valve failed to close at the start of evacuation. The tube bundle temperature was 800-900^{o}F when the inrush of air begun.

The test was stopped, and the vacuum valve removed and examined. Although sodium or its compounds were found in the valve, the amount did not seem sufficient to prevent operation. However, when the valve was cleaned and reassembled, it operated properly.

It was decided at that time to continue the test to gain as much information as possible. The system was reevacuated and the evaporation cycle was begun. Two complete cycles were made, and the system shut down.

Upon examination the following morning, the bundle was found to be free of sodium on the outside, and the failed fuel pin (with the defect) was empty. The surface of the bundle had a much heavier than normal layer of sodium compounds, especially on the end which had been exposed to the inrushing air when the valve failed to function.

Although it is not recommended that sodium-wetted components be handled in poor atmospheres containing high concentrations of oxygen and water vapor, these tests indicate that the evaporative removal process can handle humid air exposed components without difficulty.

The required processing time may be increased slightly, but not markedly. One problem which may arise is the disassembly of close-tolerance parts, bolts, etc. after exposure to humid air.

The residuals of sodium compounds on the components can be safely washed in rinse water or in decontamination solutions after complete sodium evaporation. Such washing may remove these compounds from close-tolerance parts and eliminate the problems.

III CONCLUSIONS AND RECOMMENDATIONS

It has been demonstrated that the Evaporative Removel of Sodium (ERNA) process is capable of removing sodium from a variety of shapes and sizes of components, including components which have been deliberately exposed to humid air before sodium removal. It also has been demonstrated that the process does not produce caustic stress corrosion cracking of components during sodium removal, nor was any evidence found that might cause future damage to the components.

The process has demonstrated capability of removing sodium from the internals of a failed fuel pin when coupled with an alternate cycle of argon purge.

It must be concluded that the ERNA process is worthy of future consideration as a recognized sodium removal process for reactor components.

Therefore, it is recommended that a large, process demonstration facility be designed and built to clean full size, non-radioactive fuel assemblies containing pin defects of various types, sizes and locations. Although the present tests required only a few microns pressure to remove the sodium from the section, representing only a fraction of a full scale fuel element assembly, the process demonstration facility would require a larger pumping capacity and the lower vacuum capability of Turbomolecular or Cryopumps to offset the increased surface area and the reduced conductance of the full scale assembly.

The following section presents an outline specification for a large scale sodium evaporation facility.

IV PRELIMINARY OUTLINE FACILITY SPECIFICATION

A. Scope

This specification outlines the requirements for a large facility capable of removing sodium from simulated, full-size, fuel pin assemblies which contain defects simulating failed fuel pins.

This specification is limited to the handling of non-radioactive components, and does not apply to the reprocessing or requalification of the assemblies in any manner.

B. Documents

The following documents of the exact issue shown form a part of this specification to the extent specified within the text of this specification. In the event of conflict between the following documents and the content of this specification, the content of this specification shall be considered a superseding document.

1. DOE-RDT F2-2T Calibration Program Requirements, February 1973.
2. N707TI830022, "Evaporative Removal of Sodium from Fuel Elements - Final Outline Specification," F. H. Welch, June 30, 1978.

C. Definitions

The following definitions and their special meanings shall be applicable to this specification:

1. Fuel Assembly, CRBR. An array of fuel rods into an assembly, containing the core (fuel) and the lower and upper blanket (breeder material). See Appendix 1 and Figure 7.
2. Inert Gas. Argon or helium shall be considered inert gases for the evaporative process.
3. Failed Fuel Pin. Fuel pin which has ruptured, permitting the possible entrance of sodium to the interior.

D. Process Description

The evaporative removal of sodium from the simulated non-radioactive CRBR fuel assemblies utilizes a two-cycle, repetitive process, wherein vacuum evaporation is coupled with argon purging. The vacuum evaporation is utilized to speed up the sodium removal and the argon purge is utilized to keep the fuel assembly from overheating and subsequent "meltdown".

The fuel assembly is loaded into the vacuum system under a flowing inert gas atmosphere - to cool the fuel rods. The cooling gas flow is stopped and the system rapidly evacuated using high speed, high capacity vacuum equipment. The vacuum conditions are maintained and the temperatures monitored until the fuel rods approach the prescribed maximum temperature. At this time, the vacuum equipment is isolated, and the purge of inert gas begun to cool the fuel rods. The process is repeated for as many cycles as required to remove the sodium from the assembly.

The following steps present the procedure which will be used for the evaporative removal of sodium from CRBR fuel assemblies:

1. Load Fuel Assembly

1.1 Evacuate vacuum chamber to ~10 microns or less.

1.2 Backfill with Grade 5 argon gas.

1.3 Mate fuel assembly cask with vacuum chamber, maintaining argon purge at a flow rate of 1200 lb/hr (tentative). (See Fig. 8, Curve I.)

1.4 Transfer fuel assembly to vacuum chamber and seal chamber. Maintain purge rate to cool fuel assembly.

2. Evacuate Sodium Evaporation System

2.1 Close argon inlet and exit valves.

2.2 Open vacuum valve to high speed roughing pumps (dual, 300 cfm Stokes vacuum pump may be used).

2.3 Evacuate the system to ~10 microns or less.

2.4 Continue evacuation, monitoring fuel assembly temperatures so as to not exceed 1250°F. (See Fig. 8, Curve II)

3. Argon Purge Sodium Evaporation System

3.1 Close vacuum valves

3.2 Open argon inlet and exit valves.

3.3 Cool fuel assembly with 1200 lb/hr (tentative) argon preheated to 800°F. until initial temperature profiles are reached. (See Fig. 9.)

4. Continue Vacuum-Argon Flow Cyclic Operation

4.1 Repeat cyclic operation.** Typical Cycle is shown in Table 1.

5. Unload Fuel Assembly

5.1 Mate fuel assembly cask with vacuum chamber, maintaining argon purge to cool fuel assembly.

5.2 Transfer fuel assembly into cask.

5.3 Reseal vacuum chamber.

TABLE 5

TYPICAL CYCLE

Process Step	Time, minutes (Calc. Ref. 16)	(Test Assy.)
Argon Purge	Cycle Start	
Evacuation Cycle I	2	0.5
Evacuation Cycle II (evaporation)	8	15
Argon Cooling Flow	15	30

E. Equipment Requirements

The following equipment or its approved equivalent shall be provided for the cleaning process:

1. Vacuum Chamber

A vessel of sufficient length and diameter to contain the full-size, simulated fuel assembly.

2. Roughing Pump

A mechanical vacuum pump or pumps of sufficient pumping speed to rapidly evacuate the chamber to about 10 microns. (Estimated to be $\geq$ 300 cfm or 140 l/sec).

**Tests on simulated failed fuel pins have shown the Na to be removed completely during the first vacuum cycle. Multiple cycles should be made until experience shows the minimum number of cycles required for actual components. (Ref. 21.)

3. High Vacuum Pump

   A Turbomolecular or Cryogenic type vacuum pump of sufficient pumping speed to rapidly reduce the chamber pressure to about 10^{-5}torr. (Estimated to be $\geq$ 1500 l/sec)

4. Argon Supply System

   A compressed gas system and assorted valves and gages capable of supplying a minimum of 1200 lb/hr of argon for system purge.

5. Argon Heater

   A dual system capable of heating 1200 lb/hr of argon to 800^{o}F.

6. Sodium Collector Systems

   A collection of cooled plates, etc. to condense out the Na, preventing its entrance into the vacuum pumps, or its exit into the piping.

7. Sodium Detectors (Optional)

   A device capable of monitoring the sodium vapor content of the gases to determine the end point of the evaporative process.

8. Recorders and Controllers

   A group of instruments capable of recording and/or controlling the vacuum pressure and temperatures within the system.

9. Scrubber System

   A water spray or other method of removing residual sodium vapors and aerosols to prevent release to the atmosphere.

10. Gas Cooler System

    A water-cooled argon/sodium vapor chiller to prevent damage to the high vacuum valve by the hot gases.

11. Nitrogen Supply System

    A compressed gas system to supply gaseous N_2 to a cannister or shroud protecting the simulated, failed fuel pin assembly upon removal from the sodium wetting apparatus and during its installation into the Vacuum Chamber.

11. Transportation Cannister

A metal cannister or shroud capable of holding the fuel assembly during transportation and protecting it from contamination by atmosphere air.

F. Materials

1. Argon, Grade 5 (99.999% pure)

Maximum O_2 content 1 ppm, maximum H_2O content 1 ppm.

2. Nitrogen, Grade 4.5 or better (99.99% pure)
Maximum O_2 content 10 ppm, maximum H_2O content 10 ppm.

G. Facility Description

The Failed Fuel Assembly - Sodium Evaporation Facility will be patterned after the smaller test facility, illustrated in Figure 13, and will be located in Building T042, at the Energy Systems Group, Santa Susana Facility.

The vacuum vessel will be about 18 feet long (14 feet for the fuel assembly, plus ~4 feet for other piping, connections, flanges, etc.), and will be placed horizontally, although space limitations may require the vessel to be placed vertically with the argon flow at the top and the cold trap and vacuum hardware at the bottom.

Dual Stoke's pumps will be used to rough down the larger system. These units operate at ~300 cfm or ~140 l/sec each, and will be located outside of the building because of their noisy operation.

A Turbomolecular or Cryogenic pump with a pumping speed of ~1500 l/sec will be located inside the building ahead of the roughing pumps to lower the pressure to ~10^{-5} torr.

All piping, vacuum valves, fittings, etc. which may come in contact with sodium or sodium vapors will be corrosion resistant stainless steel.

The present system of cold traps and scrubber unit, which are used to remove sodium and sodium vapors to prevent release to the vacuum components or to the atmosphere, will be redesigned to handle the larger amounts of sodium anticipated with the full size fuel assembly.

After passing through the scrubber, the argon gas will be exhausted to the atmosphere. N_2 purge gas also will be exhausted to the atmosphere.

Water from sodium collector plates, cooling jackets, etc. will be from the building water cooling system and is recirculated, but the scrubber water will be discharged to the holding pond behind Bldg. T042.

Electrical power availability will have to be increased in the area of the facility, since the present test activities have marginal power.

Gaseous Argon will be supplied to the facility from a multi-bottle cradle to be located at the rear of the building. Gaseous N_2 will be supplied from the present building system.

Wherever possible the existing Evaporative Removal test facility equipment, etc. will be used as a part of the new facility. And it is planned to use in the new facility, the Stoke's pumps and large vacuum valves and cold traps salvaged from Bldg. 59.

H. Safety Requirements

1. Sodium

Personnel involved in sodium removal shall be trained in the handling of sodium and sodium compounds, and shall be familiar with and comply with the requirements of the AI Health and Safety Document G-5, "Safe Handling of Sodium and NaK".

2. Vacuum and Gas Systems

Process personnel shall be trained in the safe operation of the vacuum equipment, argon flow systems, and the associated instrumentation, piping and valves.

All systems shall be inspected to assure that they are adequate for the intended service. Suitable over-pressure relief protection shall be provided for the argon gas system.

3. Radiation

All personnel involved in handling of radioactive fuel assemblies shall be trained in the appropriate Radiation Safety procedures, and shall follow the specific instructions of the Radiation Services personnel while processing radioactive materials. (Not applicable until system adapted to

actual fuel assemblies.)

4. Electrical and Other Hazards

Personnel shall be trained in the safe handling of all electrical equipment, and shall utilize safe, recognized laboratory procedures.

I. Quality Assurance Requirements

1. Calibration

All instruments used for control and monitoring of the sodium removal process shall be calibrated per the requirements of RDT F2-2 and shall carry a valid calibration sticker as evidence of conformance.

2. Material Acceptance

Each lot of argon or other process gases shall bear the vendor's certificate of conformance of purity.

All materials, procured for fabrication of the facility, shall, where judged critical, bear the vendor's certificate of conformance to the Purchase Requisition.

V REFERENCES

1. TID-26487, "Specialists Meeting on Decontamination of Plant Components from Sodium and Radioactivity," Dounreay Experimental Reactor Establishment, Thurso, Caithness, Scotland, 9-12 April 1973.
2. TI707-830-011, "Evaporative Removal of Sodium from Liquid Metal Fast Breeder Reactor Components - Interim Progress Report," E. Hill, March 15, 1975.
3. TI707-830-012, "Evaporative Removal of Sodium from Crevices," E. Hill, August 1, 1975.
4. N707TP830007, "The Evaporative Removal of Sodium," F. Welch, October 28, 1976.
5. N707DTP830011, "Evaporative Removal of Sodium - Test Procedure for General Sodium-Wetted Components," F. H. Welch, November 10, 1976.
6. N707TR830011, " The Evaporative Removal of Sodium-Parametric Tests", F. H. Welch, September 13, 1977.

7. AI-ERDA-13174, " Quarterly Technical Progress Report - Sodium Technology and Cover Gas Seal Development Programs", April-June 1976.

8. N707TR830013, "Evaporative Removal of Sodium: Stressed Type 304 Stainless Steel Tensile Specimens", F. Welch, October 31, 1977.

9. AI-ERDA-13165, "Quarterly Technical Progress Report - Sodium Technology and Cover Gas Seal Development Programs", October-December, 1975.

10. HEDL Report TC316, "Sodium Removal from an IHX Subscale Model at HEDL", M. D. Crippen.

11. N707TR830012, "Evaporative Removal of Sodium from the IHX Tube Bundle Mockup", F. Welch, October 26, 1977.

12. N707TI830020, "Evaporative Removal of Sodium from Components -, Preliminary Outline Specification", F. H. Welch, October 5, 1977.

13. TI-099-415-012, "Fuel Handling Cell - Hot Gas Cleaning System", R. L. Baher, August 26, 1974.

14. ANL-7520, "Sodium Evaporation in an Argon Flow", J. Van Divoot, A. Michel, and R. Lanckman, November 7, 1968.

15. ORNL-TM-4598, "The Evaporation of Sodium into an Inert Gas Sweep - An Evaluation of the Process having Application to the Deactivation of Internal Sodium in LMFBR Fuel Assemblies", W. S. Groenier and H. J. Jenkins.

16. N707TI830015, "Removal of Residual Sodium from CRBR Spent Fuel Assemblies Containing Failed Fuel Pins"", T. Shimazaki, Oct. 4, 1976.

17. N707DTP830013, "Evaporative Removal of Sodium - Test Procedure for Sodium-wetted Fuel Assemblies", F. H. Welch, February 3, 1978.

18. N707TI830019, "Evaporative Removal of Sodium from Fuel Elements - Preliminary Outline Specification," F. H. Welch, September 29, 1977.

19. N707TI830022, "Evaporative Removal of Sodium from Fuel Elements - Final Outline Specification", F. H. Welch, June 28, 1978.

20. "Sodium Removal of Fuel Elements by Vacuum Distillation", E. Buuscher, W. Haubold, W. Jansing and G. Kirchner, International Atomic Energy Agency Specialist's Meeting on Sodium Removal and Decontamination, Richland, Wa., February 14-16, 1978.

21. N707TR830015, "Evaporative Removal of Sodium from Fuel Elements - An Interim Report", F. Welch, July 17, 1978.

22. N707TP830009, "The Evaporative Removal of Sodium - Addendum to Test Plan Document N707TP830007", F. H. Welch, July 20, 1978.

23. N707DTP830014, "Evaporative Removal of Sodium - Addendum to Test Procedure N707DTP830011", F. H. Welch, July 20, 1978.